Passive Solar Design for Prescott Area Custom Homes

Passive solar design uses sunshine to heat and light homes and other buildings thereby minimizing the use of mechanical or electrical devices. It is usually part of the design of the building itself, using certain materials and placement of windows or skylights. A successful passive solar building needs to be very well insulated in order to make best use of the sun's energy. The result is a quiet and comfortable space, free of drafts and cold spots. Passive solar design can also achieve summer cooling and ventilating by making use of convective air currents which are created by the natural tendency of hot air to rise. In the winter when heating is required, the sun is low in the sky, which allows the heat to penetrate into windows on the south face of a structure. In the summer, south-facing windows can be shaded by an overhanging roof or awning to keep out the high hot summer sun. Because much of a building's heat is lost through its windows, the majority of windows in a passive solar building are located on the south wall. Depending on the climate and the design, as much as 100 percent of a building's heating needs can be provided by the sun. In Prescott's climate (2009 IECC Climate Zone 4), meeting 80 percent of a building's heating needs through sunlight can be a realistic goal given a balanced design. Even if 50 percent or 30 percent is sun-generated, conventional heating bills are cut by that amount. Prescott's winter climate is cold but sunny climate and is a very favorable location for passive solar heating. Additionally, summer comfort can often be achieved without the need for air conditioning by employing shading and natural cooling techniques.

Elements of the Passive Solar House

SITE PLANNING FOR A PASSIVE SOLAR HOUSE

Access to direct sunlight on the south-facing exposure of the home is primary to any passive solar home. Features which could block sun access include trees (including trees not yet mature), tall buildings (including future development), and hills/mountains. If a site's solar access is questionable, then a site survey can be conducted using an instrument such as the Solar Pathfinder™. This instrument is used for shade analysis and any trees, buildings, or other objects that could cast shadows are reflected in the plastic dome, clearly showing shading patterns at the site. Solar site surveys can be performed by Prescott area solar system installers.

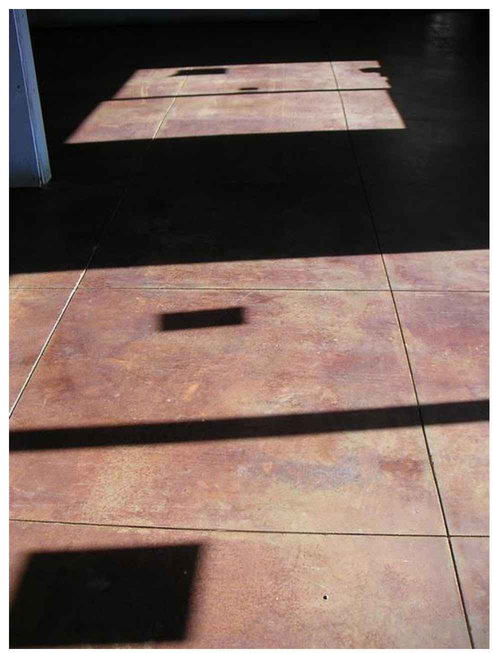
A good design balances energy performance with other important factors such as, the slope of the site, the individual house plan, the direction of prevailing breezes for summer cooling, the views, the street lay out and so on. Ideally, the glazing on the house should be exposed to sunlight with no obstructions within an arc of 60 degrees on either side of true south, but reasonably good solar access will still be guaranteed if the glazing is unshaded within an arc of 45 degrees. Buildings, trees, or other obstructions should not be located so as to shade the south wall of solar buildings. At this latitude, no structures should be allowed within 10 feet of the south wall of a solar building; fences should be located beyond 10 feet; one story buildings should be located beyond 17 feet; and two story buildings should be located beyond 40 feet.

SOUTH FACING GLASS

South facing glass, also called **glazing,** is a key component of any passive solar system in the northern hemisphere. The system must include enough solar glazing for good performance in winter, but not so much that cooling performance in summer will be compromised. When the solar glazing is tilted, its winter effectiveness as a solar collector increases. However, tilted glazing can cause serious overheating in the summer if it is not shaded very carefully. Ordinary vertical glazing is easier to shade, less likely to overheat, less susceptible to damage and leaking, and so is almost always a better year-round solution. Even in the winter, with the sun low in the sky and reflecting off snow cover, vertical glazing can often offer energy performance just as effective as tilted.

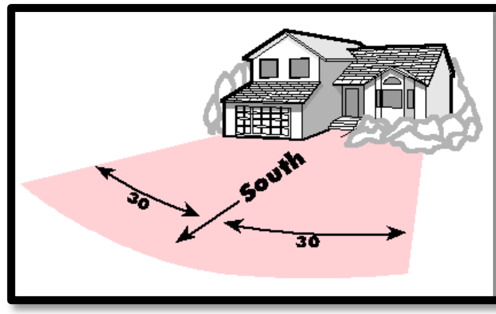
THERMAL MASS

Almost all passive solar systems work in conjunction with **thermal mass**, or materials with a high capacity for absorbing and storing heat (e.g., brick, concrete masonry, concrete slab, tile, adobe, water). Thermal mass can be incorporated into a building design as floors, interior walls, fireplaces, or bancos. The sun does not need to hit these surfaces directly to store the heat, nor do these surfaces necessarily need to be a dark color. The thermal storage capabilities of a given material depend on the material's **thermal conductivity, specific heat** and density. Conductivity tends to increase with increasing density; generally, the higher the density of the material, the better. Effective materials for floors include painted, colored or acid-etched concrete (photo), brick, quarry tile, and dark ceramic tile. When more mass is required, interior walls (photo) or interior masonry fireplaces can be incorporated into the design. Mass walls serve the dual functions of serving as structural elements or fire protection as well as for thermal storage. From an energy standpoint, it would be difficult to add too much thermal mass in a house. But thermal mass has a cost, and so adding too much mass just for thermal storage purposes can be unnecessarily expensive. As with all aspects of solar design planning, it is necessary to achieve a workable balance.



ORIENTATION

In order for passive solar systems to work effectively, care must be taken to ensure that the building is oriented to take advantage of year-round energy savings. The ideal orientation for solar glazing is within 5 degrees of true south. This orientation will provide maximum performance. Glazing oriented to within 15 degrees of true south will perform almost as well, and orientations up to 30 degrees off—although less effective—will still provide a substantial level of solar contribution. In Prescott, magnetic north as indicated on the compass is actually about 11 degrees east of true north, and this **declination** should be corrected for when planning for orientation of south glazing. When glazing is oriented more than 15 degrees off true south, not only is winter solar performance reduced, but summer air conditioning loads also significantly increase, especially as the orientation goes west. The warmer the climate, the more east and west-facing glass will tend to cause overheating problems. In general, southeast orientations present less of a problem than southwest. In the ideal situation, the house should be oriented east-west and so have its longest wall facing south. But as a practical matter, if the house's short side has good southern exposure it will usually accommodate sufficient glazing for an effective passive solar system, provided that the heat can be transferred to the northern zones of the house.



SUNTEMPERING

Suntempering is the most basic of passive solar techniques, it is simply increasing the number of windows on the south side, without adding additional thermal mass apart from the framing, gypsum board, etc, that is normally part of a conventional house. In a conventional house, about 25 percent of the windows face south which amounts to about 3 percent of the house's total floor space. In a **suntempered** house, the percentage is increased to a maximum of about 7 percent. Energy savings are modest with this system, but suntempering is very low cost.

DIRECT GAIN

The most common passive solar system is called **direct gain.** Direct gain refers to the sunlight that enters a building through windows, warming the interior space. During the sunlight hours, this heat can be stored in thermal mass incorporated into floors or interior walls made of adobe, brick, concrete, stone, or water. The heat held by the thermal mass will continue to radiate into the space after the sun goes down. Designing a direct gain system includes calculating how much window area and how much thermal mass are required to provide the desired quantity of heat for the space. In general, total direct gain glass area should be at least 7 percent, but not exceed 12 percent of the house's floor area. **Double glazing** is recommended for direct gain windows in Prescott. Night insulation, such as window shades, quilts or insulating drapes, improves **energy efficiency** dramatically.

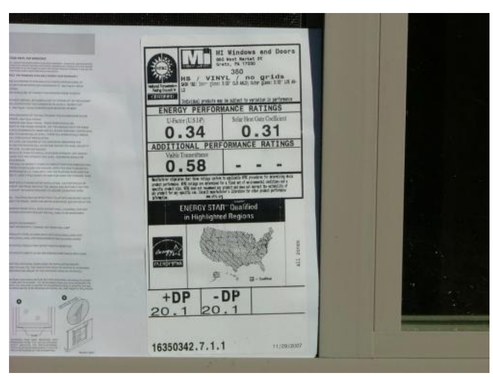
GREENHOUSES AND SUNSPACES

When built onto the south wall of a structure, a **solar greenhouse** or **sunspace** provides an insulating air cushion between the outside and inside of the building, lowering heating bills in the winter. Sunspaces are referred to as "isolated gain" passive solar systems because the sunlight is collected in an area which can be closed off from the rest of the house. During the day, the doors or windows between the sunspace and the house can be opened to circulate collected heat, and then closed at night, and the temperature in the sunspace allowed to drop. Thermal mass in the greenhouse/sunspace will also generate heat which can be moved into the building either mechanically or by designing the structure to encourage a convective air current. *Greenhouses* generally have glass or plastic panels in the roof to allow light and heat for growing plants and early seed-starting. They are difficult to insulate in areas with very cold winters because often much heat is lost through the roof, but the tradeoff is an extended growing season. *Sunspaces* usually have an insulated roof and full length windows on the south side. They are often more practical than greenhouses as living spaces, but will still provide an excellent environment for plants, and a more even temperature level throughout the year. Climate and desired use will dictate how a greenhouse or sunspace is designed for a particular application. Ventilation, roof glass, and thermal mass are important design features that make either structure a valuable money-saving and comfort-enhancing addition to a home or design. A rule of thumb for sunspaces is to incorporate 3 square feet of 4-inch thick thermal mass for each square foot of sunspace glazing. A good place for thermal mass in the sunspace is the flooring. The lower edge of the south-facing windows should be no more than 6 inches from the floor or the planter bed to make sure the mass in the floor receives sufficient direct sunlight. If the thermal mass is instead located in the commonwall, it should be solid masonry approximately 4 to 8 inches thick, or a frame wall with masonry veneer. Windows on the east and west walls are useful for cross-ventilation but should be kept small (no more than 10 percent of the total sunspace area). Double glazing is recommended for sunspaces.

ENERGY CONSERVATION: Insulation, Infiltration and Non-Solar Glazing

Adding insulation to walls, floors, ceilings, roof and foundations improves their thermal **resistance (R-value)**, or resistance to heat flowing out of the house. Ensuring that the insulation is properly installed is very important to the house's overall energy performance. Sealing the house carefully to reduce air **infiltration** (air leakage) is also essential. Air will flow rapidly through cracks and crevices in the wall in the same way that water flows through the drain in a bathtub, so even a small opening can allow heat to bypass the insulation and lead to big energy losses. The tightness of a house is generally measured in the number of air exchanges per hour (ACH). A good, comfortable, energy efficient house will have approximately 0.35 to 0.50 air exchanges per hour under normal winter conditions. Increasing the tightness of the house beyond that may improve energy performance, but it may also create problems with indoor air quality, moisture build-up, and inadequately vented fireplaces and furnaces. Some kind of additional mechanical ventilation—for example, small fans, heat pump heat exchangers, integrated ventilation systems or air-to-air heat exchangers—is usually necessary to avoid such problems in houses with less than 0.35 ACH.

Windows that are not south facing are considered non-solar glazing. Windows on the north side of a house in almost every climate lose significant heat energy and gain very little useful sunlight in the winter. East and west windows are likely to increase air conditioning needs unless heat gain is minimized with careful attention to shading.



Light tubes (photo) should be considered instead of skylights as a energy-efficient method to provide light to a window-less room. Of course, people want windows for reasons other than energy gain, so a good design will be a balance between efficiency and other benefits, such as views and bright living spaces. Some rules of thumb for non-solar glazing: low-e ("e" stands for **emissivity**) coating will reduce heat loss while allowing for light to enter; north facing windows should be small and have high insulation or R-value; east windows catch the morning sun and can cause potential overheating, therefore shading should be planned with care; west windows also have a high potential for overheating, tinted glass or low-e glass may be effective; and lastly, as many windows as possible should be kept operable for easy natural ventilation in summer.

AIR SEALING AND AIR INFILTRATION CHECKLISTS:

- Air Sealing Technology Fact Sheet from the Department of Energy Building America Program
- New Air Sealing Requirements in the International Residential Code 2009
- Oikos Advanced Air Sealing Index
- Air sealing photo compilation

BACK UP AND MECHANICAL SYSTEMS

The passive solar features in a house and the mechanical heating, ventilating and air conditioning systems (HVAC) will interact all year round so the most effective approach is to design the system as an integrated whole.

System Sizing

Mechanical systems are often oversized for the relatively low heating loads in well-insulated passive solar houses. Oversized systems will cost more in the first place, and will cycle on and off more often, wasting energy and inefficiently removing moisture from the home. Heat load calculations should be performed by the HVAC contractor using ACCA Manual J and the back-up systems in passive solar houses should be sized to provide 100 percent of the heating or cooling load on the design day, but no larger.

Night Setback

Clock thermostats for automatic night shutoff are usually very effective, but in passive solar systems with large amounts of thermal mass releasing heat during the night, night setback of the thermostat may not save very much energy.

Ducts for Forced Air HVAC Systems

Both the supply and return ducts should ideally be located within insulated areas, or be well-insulated if they run in unconditioned areas of the house (e.g., attic or crawlspace). Ductwork joints (and the air handler) should be sealed with mastic to limit the air leakage to no more than 3% of the conditioned floor space in CFM.

Ventilation System

Modern homes and especially passive solar homes are constructed to be as tight as possible meaning that air leakage from the outside to the interior … and the opposite direction … is minimized. However, this can create interior air quality issues e.g., stale air, cooking odors, moisture accumulation. Ideally a balanced ventilation system should be installed that expels stale interior air and draws in/distributes tempered exterior air.

INTERIOR SPACE PLANNING

Planning room lay out by considering how the rooms will be used in different seasons, and at different times of the day, can save energy and increase comfort. In houses with passive solar features, the lay out of rooms and interior zones is particularly important. A longer East-West axis will allow more rooms to face south. In general, living areas and other high-activity rooms should be located on the south side to benefit from the solar heat. The closets, storage areas, garage and other less-used rooms can act as buffers along the north side, but entryways should be located away from the wind. Locating baths, kitchens and laundry rooms within a 30 ft plumbing run of the hotwater storage will save the heat that would be lost from longer water line runs. Another general principle is that an open floor plan will allow the collected solar heat to circulate freely through natural convection.

Other ideas include:

- orienting internal mass walls as north-south partitions that can be "charged" on both sides thus making maximum use of the mass.
- using an east-west partition wall for thermal mass, but avoid dividing the interior space into a north zone that may get too cold and south zone that may get too warm
- using thermal storage walls
- collecting the solar energy in one zone of the house and transporting it to another by fans, natural convection and/or an open floor plan
- providing south-facing **clerestories** to "charge" north zones.

NATURAL COOLING GUIDELINES

"Natural cooling" refers to techniques which help a house stay cool in the summer but which require little to no energy. Such techniques help to reduce air conditioning, not replace it. Shading is particularly important in passive solar houses, because the same features that collect sunlight in winter will go right on collecting it in summer unless they are shaded and the house itself is designed to help cool itself. Thermal mass performs well year round, masonry materials can be effective in staying cool as well as storing heat in winter. If mass surfaces are exposed to cool night time temperatures, they will help the house stay cooler the next day. The additional insulation that increases winter performance will also work to improve summer performance by conserving the conditioned air inside the house. Some low-e windows and other glazes with high R-values can help shield against unwanted heat gain in summer.

SHADING

Landscaping

Trees and other landscaping features may be effectively used to shade east and west windows from summer solar gains. Trees on the southside, however, can all but eliminate passive solar performance, unless they are very close to the house and the lower branches can be removed to allow the winter sun to penetrate under the tree canopy. If a careful study of shading patterns is done before construction, it should be possible to accommodate the south-facing glazing while leaving in as many trees as possible. Other landscaping ideas for summer shade include: trellises on the east and west covered with vines; shrubbery or other plantings to shade paved areas; use of ground cover to prevent glare and heat absorption; trees, fences, or shrubbery planted so as to "channel" breezes into the house; and deciduous trees on the east and west sides of the house, to balance solar gains in all seasons.

Roof Overhangs

Fixed overhangs are an inexpensive feature and require no operation by the homeowner. They must be carefully designed, however. Otherwise, an overhang that blocks the summer sun may also block sun in the spring, when solar heating is desired. Likewise, an overhang sized for maximum solar gain in winter will allow solar gain in the fall on hot days. A combination of carefully sized overhangs on south windows and shading devices on the other windows usually allows for an effective solution. The following figure may be used to determine the optimum overhang size. This website provides several calculators for determining sun angle and eave overhang dimensions.

Shading Devices

External devices stop solar gain before the sun hits the building. These include awnings, solar screens, roll-down blinds, shutters and vertical louvers. They are adjustable and perform well, but require action by the homeowner to operate. Interior shading elements also require homeowner operation, and also permit the sun to enter the house and be trapped between the window and the shade. Reflective interior blinds and curtains are relatively low cost and are easy to operate. Another option in shading is a porch or carport, preferably located on the east or west sides.

VENTILATION

When possible, the house should be positioned on the site to take advantage of prevailing winds. The prevailing winds direction is from the south during the summer. The free vent area (unobstructed openings like open windows) should be between 6 to 7.5 percent of total floor area, half located on the leeward and half on the windward side of the building. Ceiling fans will probably save more energy than any other single cooling strategy, since air movement can make people feel comfortable at higher temperatures. A whole house fan is particularly effective with the large diurnal temperature swings in the Prescott summer months, but is not very effective at cooling when the night-time temperature is higher than 76 degrees F.

Using a combination of the above cooling techniques will substantially reduce the need for air conditioning.

PASSIVE SOLAR DESIGN CHECKLIST

1. Is the house **oriented** to optimize both winter heating and summer cooling needs?
2. Does the house effectively incorporate sufficient **thermal mass**?
3. Does the house design include thorough **insulation** throughout?
4. Does the house design optimize **glazing** so as not to over or underheat?
5. Is the **backup heat system** appropriately sized?
6. Does the **interior design** maximize solar heating and cooling benefits?

Adapted from the New Mexico Solar Energy Association website www.nmsea.org